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WHEAT VARIETIES AND THE ENERGY RETENTION OF BROILER CHICKENS

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A thesis submitted in partial fulfilment of the requirements of the Open University for the degree of Bachelor of Philosophy

April 1997

Harper Adams Agricultural College

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DECLARATION

This thesis was composed by the author, and is a record of work carried out by him on an original line of research. All sources of information are shown in the texts and listed in the references: all help given by others is indicated in the acknowledgments.

None of this work has been presented in any previous application for a degree.

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Contents

List of Tables

List of Figures

Abstract

There are differences in the productive performance of growing chickens fed different wheat samples, but these are not correlated with the determined metabolisable energies of the wheat samples. It is possible that metabolisable energy does not adequately describe the net energy of different wheat samples. The objectives of this experiment were to determine whether there are differences in the energy retention of broiler chickens fed 6 different wheat varieties grown in three field blocks and to assess whether these differences are correlated to differences in productive performance.

A crop growth trial at Harper Adams College produced samples of 6 different UK wheat varieties (Dean, Brigadier, Beaver, Rialto, Riband and Haven) each from three different positional blocks in the 1994 harvest. Each of the 18 wheat samples was included at 650 g/kg in a pelleted broiler food that had a calculated composition of 225 g/kg crude protein and 12.5 MJ/kg of metabolisable energy. Each diet was fed to 4 cages of broiler chickens from 7 to 21 days of age. Each cage had a floor area of 0.1 m^2 and contained two birds. Metabolisable energy was determined by collecting all excreta produced during the 4 days of the feeding period and energy retention was

determined by gross energy analysis of carcases.

The 18 wheat samples had similar chemical compositions with ranges of 867 to 876 g dry matter/kg, 114 to 160 g crude protein/kg dry matter, 18.3 to 19.1 MJ of gross energy/kg dry matter and specific weights of 75.9 to 78.7 kg/hl. There were no differences ($P>0.05$) in any of the measured variables of broiler growth or energy availability between the wheat samples grown in the three different field blocks. There were no ($P>0.05$) differences in AME_N between the 6 varieties, yet differences in energy retention ($P<0.01$) were significantly ($P<0.01$) correlated to the differences in food conversion ratio ($P<0.05$) and weight gain ($P<0.05$).

Although some wheat samples do vary in their ME, there are few differences in ME between Autumn sown wheat varieties produced in the UK. This experiment also showed no difference in ME between the wheat samples but that wheat variety affected the energy retention of the broilers per MJ of ME intake. The experiment indicates that there were differences in the net energy of 6 UK wheat varieties that were correlated to differences in the productive performance of broilers, but these nutritional differences were not detected by metabolisable energy determinations, digesta viscosity or determined chemical analysis of the wheat samples.

1. Introduction.

Wheat is used as the major energy source in poultry diets throughout most of Europe. This is due to a number of factors. First, wheat can be grown on a wide range of soil types, geographical locations and latitudes. Second, it is an excellent source of energy with up to 80% of the grain being starch. (Pomeranz, 1988). Third, poultry are able to digest wheat readily, even if fed as whole wheat grains, (Rose, 1995), which has big economic benefits to the farmer growing his own grain. Fourth, wheat is relatively cheap to produce and to buy, and this frequently makes it the cereal with the lowest cost of available energy per unit weight.

High dietary levels of wheat may cause problems, espccially in young birds due to the presence of pentosans at between 5 - 8%. (Leeson & Summers, 1997). Some of these problems can be tackled with the use exogenous xylanase enzymes to help reduce viscosity. (Bedford, 1996, 1992. Choct *et al* 1994. Classen & Bedford, 1991).

Feed is the highest cost of poultry production and as wheat makes up the largest proportion of most poultry diets, it is important for producers to know the best varieties to use and how to overcome any potential problems.

Experimental work has shown that different wheat varieties have variable effects on the productive performance of broilers. (Waldron *et al* 1993; Waldron *et al* 1994; Waldron *et al*, 1995; Rose *et al*, 1993; March & Biely, 1973; McNab, 1991). Much attention has been centred around the non-starch polysaccharide (NSP) content of the wheat. In wheat grains these are predominantly arabinoxylans. The anti-nutritional effects of these arabinoxylans were first identified when attempts were made to formulate poultry feeds using rye. In rye grains arabinoxylans were found in quantities of up to 100 g/kg (Antoniou *et al*, 1981). When isolated and fed to poultry it was found that broiler growth was depressed (Antoniou & Marquardt, 1981; Ward & Marquardt, 1987). Similar effects were found in wheat and AME values have been negatively correlated to soluble NSP levels (Annison, 1993). The quantities of pentosans found in wheat grains ranges from 50 - 80 g/kg DM (Annison, 1993). The water soluble arabinoxylans have high molecular weights and will form highly viscous aqueous solutions (Voragen et al 1992). Further work has shown that digesta viscosity increases have been linked to soluble pentosans (Choct & Annison 1992).

There have been a number of suggested theories as to the method of how

soluble NSP inhibit digestion/absorption. Annison (1993) proposed that the method of inhibition was by the interruption of digestion/absorption of enzymes, substrates and their products. Ikeda & Kusano (1983) suggested that the enzymes could be complexed by the NSP. The gut microflora are also thought to be influential, the theory being that an increase of un-digested starch, protein and fat entering the hindgut would cause proliferation of the micro-organism populations that could be detrimental to the bird (Annison 1993). This links in with the findings of Rogel *et al* (1987) who found the AME of wheats to be strongly correlated to starch digestibility (Mollah, 1980).

Differences in productive performances of growing broilers fed different wheat samples are not correlated with the determined metabolisable energies of the wheat samples. (Rose & Bedford, 1995). Metabolisable energy may not be a sufficient indicator of the nutritional value of wheat, due to other factors, either physical or chemical properties of the wheat or the gastrointestinal tract. Net energy or the energy retention may correlate better with productive performance differences.

The project had the following objectives:

1. To compare the growth, feed conversion ratio and energy retention of broiler chickens fed six UK wheat varieties.

2. To compare the variation of wheat samples from different trial blocks in the same growing season.

3. To compare the relationship between growth, feed intake, feed conversion ratio and energy retention with the chemical composition and physical characteristics of the wheat samples.

2. Review of the Literature

2.1. The Importance of Wheat in Poultry Feeds.

According to a United Nations study cereal grains supply 68% of the world's food supplies, directly, or indirectly. (Oleson, 1994). Average total world production of cereal grains was about 1.661 billion tonnes, (1986 to 1990). Out of this total wheat is the most important, with production averaging at about 533 billion tonnes annually, (1986 - 1990), which accounts for about 30 % of the total cereal production. (Oleson, 1994, Matz, 1991). Out of this total amount of wheat produced, about one fifth is used in animal feeds.

2.1.1 The Origin of Wheat

Wheat has one of the longest histories of growth and development of all crops. It is thought to have first been cultivated intentionally as a crop between 10,000 and 8,000 BC. (Orth & Shellenberger, 1984). There is a lack of certainty about the origins of modern wheat. Evidence suggests a development from a wild grass species originating in Asia Minor. (Orth &

Shellenberger, 1984). Modern bread wheat is thought to have originated through a two stage hybridization, according to Percival (1921). These developments led to wheat having the required protein components for bread making and for its ability to be cultivated over a wide area.

Though wheat was an important cereal during the early and middle ages of the millennium, both barley and rye were more extensively grown. Barley and rye were important as animal feed as well as for human consumption, whereas wheat tended to be used solely for human consumption. (Orth & Shellenberg, 1984). It was not until this century that wheat became the dominant cereal in many areas and regarded as the cereal with the widest spread of uses and quality.

2.1.2. Wheat Production.

The adaptability of wheat to be grown in such a wide range of climatic conditions is one factor that has led to its current position of importance. The main area in which wheat cultivation is concentrated is between the latitudes of 30°N and 60°N and 27°S and 40°S. The extremes of latitude at which wheat can be grown is best demonstrated in the Northern hemisphere

where wheat can be grown from the edge of the Arctic circle to the equator, with use of variation in altitude.(Nuttonson, 1955, Percival, 1921).

Wheat is a rich source of nutrients, being the main provider of carbohydrates and also of a number of required minerals, vitamins and amino acids. The nutrients contained in wheat are generally well digested with the exception of phosphorus. (Briggle & Curtis 1987).

2.1.3. Use of Wheat for Poultry Feed.

The quantity of wheat used for animal feed varies according to its price relationship with alternatives, mainly maize. Wheat is especially important in this country and much of Europe as the major component of poultry feed. Over the past 20 or so years cereals have been included in poultry diets at levels of up to 75%, (Briggle & Curtis 1987). Wheat is the preferred cereal for economic and nutritional reasons. The economic importance is that wheat for poultry feed makes up 70% of the cost of poultry feed. (McNab 1991). This is illustrated by the fact that in the UK the cost of feed accounts for 70% of total costs and wheat comprises between 60 to 75% of the diet. (McNab 1991). The effect of variety differences in terms of both productive

performance and costs is therefore very important.

In nutritional terms wheat in the diet could supply up to 80% ME and 40% of amino acid requirements, (McNab, 1991). In reality the average inclusion of wheat in poultry diets in the UK is 55 to 70%. The average provision of ME is 55% and 35% of the birds' protein requirement is also provided. (McNab 1991).

Whole wheat grains can be efficiently digested by chickens (Rose, 1995). This means that wheat can be successfully admixed to a standard pelleted balancer diet, at a level up to 50%. Usually though it is included whole at much lower levels than that, more typical would be 20% or less. (Farrant 1993).

2.2. Wheat Grain Structure.

In botanical terms the wheat grain is a single-seeded fruit, known as a caryopsis. (Evers & Bechtel. 1988)

The grain can be divided into two parts, the pericarp, (fruit coat), and the

seed. The pericarp consists of the outer pericarp, which is the outer epidermis, (epicarp), hypodermis and the inner pericarp. The seed consists of the seed coat (testa) and pigment strand, the nucellar epidermis (hyaline layer), the endosperm (aleurone layer and starchy endosperm), the embryo (embryonic axis and scutellum). The bran fraction is composed of all but the endosperm and the embryo, the endosperm forms the flour fraction and the embryo the germ.

2.2.1. The Pericarp.

The pericarp is the dead ovary wall consisting of the outer epidermis, hypodermis, parenchyma, intermediate cells, cross cells, and tube cells.

The outer epidermis is composed of long narrow cells and is generally 15 - 20 um. The dimensions and shapes of these cells varies according to the cultivar and the location. At the apex the cells are formed into hairs, (trichomes), which form the brush. The epidermis is a continual coat apart from the point of attachment to the rachilla. Water can penetrate the epidermis in the mature grain, despite the cells being cuticularized. The main point of water absorption occurs where the epidermis is thinnest

around the embryo. (Evers & Bechtel. 1988).

The hypodermis is positioned below the epidermis, being the third component of the pericarp along with the epidermis and the thin-walled parenchyma. The structure is like that of the epidermis, though has more to do with thin-walled parenchyma during development.

The thin-walled parenchyma are found below the hypodermis and play an important role during the development of the grain. The layer starts at being between 15 - 20 cells in depth at the time of anthesis and works as both a protective and supportive structure for the endosperm and the embryo. During the development of the grain the parenchyma go through a process of degeneration, with only the cross cell layer persisting to maturity. (Evers & Bechtel. 1988).

Together the pericarp, epidermis and thin-walled parenchyma are termed the "beeswing" in milling terms and make up part of the bran mill fraction.

2.2.2. Endosperm.

The majority of the grain is composed of the endosperm, which is made up of the aleurone cells and the starchy endosperm. The aleurone cells are generally only one cell in thickness in the mature wheat grain. They make up the outer layer of the endosperm.

The development of the cellular endosperm begins about 3 days from pollination. The starchy endosperm cells will continue to divide for between 16 - 20 days from anthesis, after that the cells will continue to enlarge until about 35 days. (Lersten, 1987).The aleurone cells make up the outer layer of the endosperm. They are the only part of the endosperm to be still alive at the point of maturity. The aleurone layer is looked upon as part of the bran fraction for milling and feed purposes. (Lersten, 1987).

Cells of the starchy endosperm are classified according to shape, size and site. The cells found adjoining the aleurone layer are termed the peripheral or the subaleurone cells and are of a similar size to the aleurone layer cells. The thickness of the cell wall depends upon the position of the cell in the endosperm. The cells furthest out, the peripheral cells, have the thickest cell

walls, at about 4 to 7 um thick. In other central parts of the endosperm the cell wall thickness averages about 2.6 um (Larkin et al 1952). The cell walls of the endosperm have been found to contain 15% protein and 75% polysaccharides, of which 85% is arabinoxylan, B-Glucan and B-Glucomannan. (Evers & Bechtel. 1988).

Table 1. Grain Components and Mill Fractions. (Pomeranz 1988).

Grain Component	Mill Fraction	
Grain (caryopsis)		
1. Pericarp (fruit coat)	Beeswing	Bran
(a) Outer pericarp.	Beeswing	Bran
Outer epidermis (epicarp)	Beeswing	Bran
Hypodermis	Beeswing	Bran
Thin-walled parenchyma.	Beeswing	Bran
(b) Inner Pericarp		Bran
Intermediate cells		Bran
Cross cells		Bran
Tube cells (inner epidermis)		Bran
2. Seed		
(a) Seed coat (testa) and pigment strand		Bran
(b) Nucellar epidermis (hyaline layer)		Bran
(c) Endosperm		
Aleurone layer		Bran
Starchy endosperm		White flour
(d) Embryo		
Embryonic axis		Germ
Scutellum		Germ

The endosperm cells contain mostly starch and protein, however the position of the cell determines the levels at which starch is found. The lowest starch levels are in the cells that are found closest to the peripheral layer. Protein content stays relatively consistent, therefore these cells have a higher proportion of protein. This can be as high as 54% in peripheral cells as found by Kent (1966). Towards the centre of the grain cheeks the proportion of starch increases to the other cell contents.

Apart from in the peripheral layers, where there is just the one type, there are two types of starch granules, large granules that are lens-shaped and small granules that are rounded. (Pomeranz, 1988).

2.2.3. Starchy Endosperm.

The starch in the wheat grain is the principle store of carbohydrate. As mentioned, at maturity the starch is composed of two types of granules, known as type A and type B. Type A granules are the large granules initially formed in the cytoplasm after the cellularization of the endosperm (Pomeranz, 1988). The final number of type A granules present in the endosperm depends on the number of plastids, organelles forming all plant

starch, that are present at the end of cell division. The sizes of the type A granules vary from between 30 to 50 um, (Pomeranz, 1988), and are likely to be dependant on the cultivar and the growth environment.

2.2.4. The Embryo.

Also called the germ, the embryo is located on the lower dorsal side of the caryopsis and is composed of two main parts, the embryonic axis and the scutellum. (Pomeranz, 1988).

The axis can be further divided into the epicotyl, the mesocotyl and the radicle. These are basically the part of the grain that will develop into the plant. The scutellum is a large storage organ for protein, phytin and lipid droplets.

2.3. Composition of the Wheat Grain.

Wheat in poultry diets is utilised as whole grain as opposed to being graded into mill fractions. About 70% of the wheat grain is carbohydrate, the next largest component being protein, at 10 to 15%.

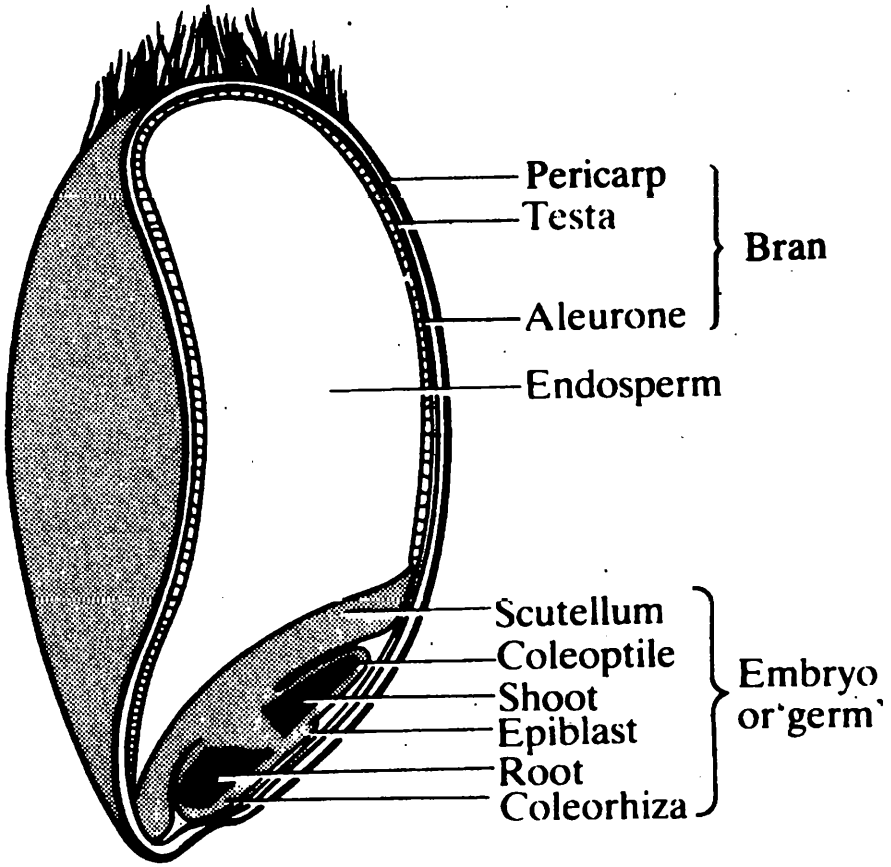


Figure 2.1 Section of a wheat grain.

2.3.1. Protein.

Almost all the protein is formed by the extraction of soluble nitrogen compounds extracted from soil by the roots. A series of enzymatic processes transform these compounds to proteins. These proteins then form part of the structural and protective tissues of the seed. They are also found as enzymes and as storage proteins. (Matz, 1991).

The wheat proteins are complex, the storage proteins are the source of gluten, a mixture of glutenin and gliadin. The embryo, aleurone layer and the endosperm contain the proteins with enzymatic activity.

Protein will depend on both the variety of the wheat and the climatic conditions under which it is grown. Generally protein content will range between 6% and 20%. (Halverson & Zeleny 1988). More typical would be hard winter wheat between 11 to 15%, soft winter wheat between 7 to 11% protein. (Matz, 1991).

The nutritional value of wheat protein is limited by the amino acid lysine.

2.3.2. Carbohydrates.

2.3.3. Starch

Starch makes up the largest proportion of the mature wheat grain , almost 80% of the total dry matter, (Pomeranz, 1988). The starch is the primary source of energy and the main reason for wheat being a valued source of nutrition.

Starch is a polysaccharide composed of a polymer of D-glucose. Amylose and amylopectin are present in varying proportions, (Matz, 1991).

Starch granules have been classified into three different classes according to their size and time of development, (Bechtal *et al.,* 1990). Basically class A granules devlope first in the grain and and become the largest type, followed by type B and finally type C. Only a small percentage of the starch granules are of type C, type A making up just over 50%, and type B just under 50% typically. However, there is variation amongst wheat types and varieties, in the proportion of starch grain type. The 'soft' and feed wheats tend to have more of the B and C type granules than 'hard' milling varieties, (Bechtal *et al.,* 1990)

It is the polysaccharides other than the starch that are relevant to this study. These are to be found in the cell walls of the parenchymatous and lignified tissues. (Matz 1991). These polysaccharides are mostly the pentosans arabinoxylan and B-D-glucan. In wheat, arabinoxylan is present in much larger quantities than the B-D-glucans, which are only found in very small quantities in the wheat grain. Cellulose is also present in the cell walls of the lignified bran layers. Table 2 below lists sugars and polysaccharides found in the wheat kernel.

Table 2.2 Sugars and Polysaccharides in Wheat Kernels

(% of total DM of Kernel)

Sugars		**Polysaccharides**	
Component	**Content**	**Component**	**Content**
Glucofructosans	0.94 - 1.14	Starch	62.9 - 75.0
Sucrose	0.54 - 1.55	**Pentosans**	**5.57 - 9.00**
Glucose	0.03 - 0.09		
Raffinose	0.19 - 0.68		
Fructose	0.06 - 0.08		
Glucodifructose	0.26 - 0.41		
Galactose	0.02		
Maltose	0.01 - 0.18		

(Matz, 1991)

2.3.3. Non-Starch Polysaccharides.

The non-starch polysaccharides fraction of the wheat grain has also become known as dietary fibre and has become a much researched and discussed subject lately, both in terms of human nutrition, animal and more specifically poultry nutrition, due to the importance of wheat as a poultry feed.

The non-starch polysaccharides are the main constituents of the plant cell walls and all lignified tissues. (Pomeranz, 1988). They are arabinoxylans, soluble (1 - 3)(1 - 4) - B - D - glucans and cellulose. Arabinoxylans make up approximately 88% of the endosperm cell wall polysaccharides, of these 30 to 50% are water soluble. (Pomeranz, 1988). The arabinoxylans share many characteristics with B-glucan, consisting of a backbone of B-1, 4 - linked xylopyranosyl residues with terminal 1,2 and 1,3 arabinofuranosyl substitutions. (Bedford & Classen, 1991). It is the arabinofuranosyl substitutions that result in water soluble fractions, that are highly viscous. Generally speaking it is the arabinoxylans in the bran or outer aleurone layers that are less water soluble than those in the endosperm, due to less arabinofuranosyl substitutions. (Bedford & Classen, 1991). The non-starch polysaccharides fraction are often collectively referred to as the pentosans.

Water soluble arabinoxylans form highly viscous aqueous solutions, due to their high molecular weight and the fact that they can absorb up to ten times their own weight in water. (Voragen *et al.*, 1992). It is this effect on gut viscosity that has highlighted the importance that this small but significant fraction of the grain has on poultry nutrition.

Cellulose accounts for just 4% of the cell wall in the starchy endosperm, it is mainly found in the bran fraction cell walls where it accounts for approximately 29% of the non-starch polysaccharides. (Fincher & Stone, 1986)

Table 2.3 Composition of Four Cereals Used For Poultry Nutrition.

(NRC, 1994)

% unless stated	Wheat	Barley	Maize	Oats
DryMatter	89	89	89	89
M E (kj)	13.05	11.05	14.02	10.67
Protein	11.5	11.0	8.5	11.4
Ether Extract	2.5	1.8	3.8	4.2
Linoleic acid	-	0.83	2.20	1.47
Crude fibre	3.0	5.5	2.2	10.8
Valine	0.44	0.52	0.40	0.68
Leucine	0.59	0.76	1.00	0.89
Iso-leucine	0.42	0.37	0.29	0.52
Threonine	0.32	0.37	0.29	0.43
Tyrosine	0.39	0.35	0.30	0.53
Methionine	0.15	0.18	0.18	0.18
Lysine	0.31	0.40	0.26	0.50
Hystidine	0.42	0.27	0.23	0.24
Tryptophan	0.12	0.14	0.06	0.43
Phenylalanine	0.45	0.56	0.38	0.59

2.4 Feeding Value of Wheat for Poultry.

The importance of wheat to the UK poultry industry, in particular the broiler industry, can not be underestimated. The combined facts that there are over 450 million broilers produced in the UK each year (MAFF 1995), and that these will be eating diets typically containing between 40 and 70% wheat.

The nutritional value of wheat is therefore of great importance. If a certain wheat variety results in better growth performance than another variety at similar prices, then the farmer will want to buy that variety, or more importantly those growing their own wheat crops will want to plant those wheats. Feed compounders may also request specific varieties.

2.4.1. Metabolisable Energy.

The term apparent metabolisable energy, (AME), is used to describe the nutritional value of a diet through animal experiment. AME takes into account the fact that gross energy of a feed substance does not adequately describe the amount of energy utilised by the animal. AME is the gross energy less the energy that is lost through urine and faeces, in birds. The

AME value can be corrected for nitrogen excreted in the faeces and urine, (AMEn). This accounts for the amino acids that are not used by the animal for protein synthesis, but are de-aminated and excreted as nitrogen or urea.

There is also an energy loss through what is termed the heat increment. This refers to the increase in body heat over its basal level, as a direct result of the ingestion of food. This heat results from the inefficiency of the reactions by which nutrients are metabolised and the process of digestion which also requires energy and correspondingly heat losses. (McDonald *et al.*, 1988).

The following equation is used to calculate AME

$$\text{AME (MJ/kg)} = \frac{\text{(Energy intake (MJ) - energy excreted (MJ)}}{\text{Feed Intake (kg)}}$$

The AME method was further improved in accuracy by the developement of the Total Metabolisable Energy, (TME), method. To calculate the TME birds are fed a meal of a known amount that is fed via a tube. This gives an accurate measure of feed intake, whearas AME is subject to feed intake inaccuracies. (Sibbald, 1989).

Figure 2.2 The Partition of Food Energy in the Chicken

(MacDonald et al, 1988)

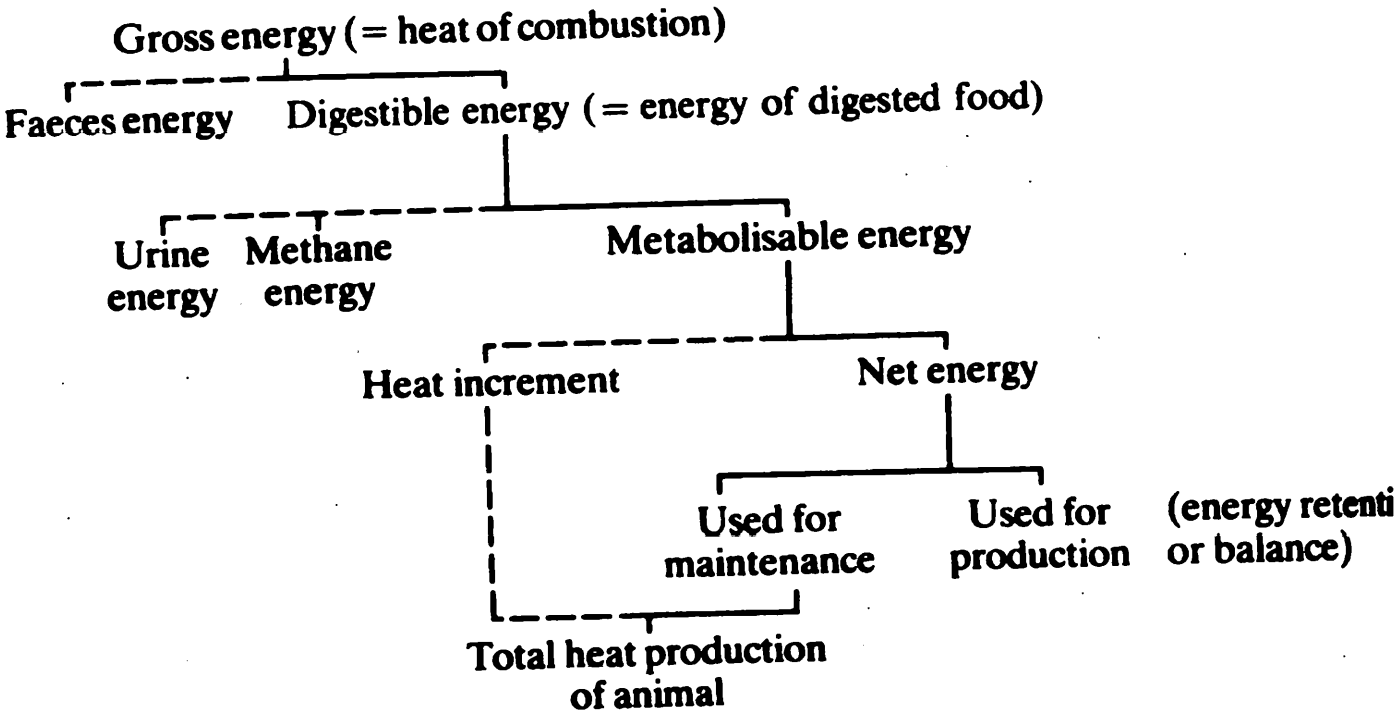


Table 2.4 Metabolisable Energy Values of Wheat for Poultry (MJ/kg)

(Wiseman 1990)

Author	Year	Sample Size	Term	Age	Data
Hil *et al*	1960	5	AMEn	chicks	14.82 - 15.72
Siebald & Slinger	1962	25	AMEn	chicks	12.32 - 16.57
Schumaier & McGinnis	1967	7	AMEn	chicks	12.05 - 13.47
March & Biely	1973	33	AMEn	chicks	13.31 - 15.86
Sibbald & Price	1976	34	AMEn	adults	13.60 - 15.56
Coates *et al*	1977	16	AMEn	chicks	13.60 - 15.06
Davidson *et al*	1978	16	AMEn	adults chicks	14.43 - 15.94 13.1 - 14.0
Mollah *et al*	1983	22	AMEn	chicks	11.0 - 15.9
Longstaff & McNab	1986	6	TMEn (as fed)	adults	15.17 - 15.65
Rogel *et al*	1987	38	AMEn	chicks	10.35 - 14.81

To ensure that this is a correct amount of intake, feed is removed from the bird for 24 hours prior to the experiment. The excreta is then collected over the next 48 hours. Control birds are also used and fed pure carbohydrate, generally in the form of a glucose or sucrose solution. The reason for this is that it gives a measure of the non-dietary energy lost from the gut. This is calculated as endogenous energy loss (EEL). Corrections are made for nitrogen as with AME and the following equaiton is then used for TMEn. (Rose, 1997)

$$TMEn = \frac{(E\ In\ (MJ) - E\ out\ (MJ) + EEL(MJ) - (ret\ N\ (kg) \times 34.3925\ MJ/kg)}{Feed\ Intake\ (kg)}$$

There are a number of problems associated with the above methods. AME is widely used as an indicator of nutritional quality, though it is an inaccurate system simply through feed that is wasted by the birds, ie. dropped on the floor, into the waste trays etc that in the calculations appears as feed intake. There is also no accounting for wasted energy through heat and requirements for maintenance. It is also known that energy is utilised by the gut microflora populations of the hindgut. (Rose, 1995, Choct & Annison, 1992).

Variation in AME values have been found, in Ausrtralia (Rogel *et al.*, 1987). Such variation was not found in UK varieties that were comprehensively studied by McNab in his 1991 report for the HGCA. Also no correlation has been found between the AME values of wheat and productive performance in broilers, in the UK. (Rose & Bedford 1995). This study did find that there were differences in productive performance of broilers fed different wheat varieties yet they fouond no correlation with the AME values.

The effect of environmental factors at harvest on the energy value of wheat have been studied. Sibbald & Price (1962) found that there was no correlation between AME values and sprouting or mouldy grain. However, it seems that if germination of the grain has been allowed to continue until it is severe, a reduction in starch and protein digestibility can occur. (Batterham *et al* 1976).

2.4.2.Net Energy and Energy Retention.

The term net energy is derived by taking away the heat increment from the metabolisable energy. This could then be termed the energy available for useful purposes, maintenance and production. (MacDonald *et al.*, 1988). Some of this net energy will also leave the body as heat, as a by-product of maintenance. The remainder of the energy will be retained in the body in some form giving the term energy retention. This energy retention is also known as the productive energy, the energy that is stored in the body as fat, protein etc, according to Fraps, (1946). Much work was done on the net energy/productive energy for chickens by Fraps, Olsson (1950), Halnan (1951) and Carpenter and Clegg (1956).

2.4.3. Carbohydrate.

2.4.4. Starch

Starch quantity can vary quite widely between variety and according to climatic conditions. For example Aman (1988) found between 60.4% to 73.2% (dm) for 74 spring varieties and 65.7% to 71.8% (dm) for 41 winter wheats. Wheat is relatively low in its non-starch polysaccharide content,

compared with rye and barley, having typical ranges between 10.5% to 13.8% (total 'fibre' dm) 12 spring varieties and 10% to 10.6% (total 'fibre' dm), 12 winter varieties (Aman (1988).

There has been much evaluation of the digestibility of wheat grain starch by poulty. Though variations in starch digestibility have been found by Mollah *et al.*, 1988 and Rogel *et al.*, 1987, a large number of studies have found that it was completely digestible. Bolton (1955), Longstaff & McNab (1986) and also Rogel *et al* 1987 found that isolated wheat starch was digested readily in the chick by alpha-amylase. This was found to be true from wheat having a low AME which leads to the conclusion that starch is readily digestible, but that there may be other factors inhibitibg it. (Wiseman 1990).

It would be expected that the starch content of the grain would have a direct relationship to the AME value as it is such a high energy yielding component of the grain. However, a correlation between the starch content and AME has never been made. (Wiseman, 1990).

2.4.4. Non-starch Polysaccharides

The non-starch polysaccharide, (NSP), fraction of the wheat grain has attracted much attention in recent years due to links made between NSP and anti-nutritive effects of wheat on nutrition. It was thought that NSP had a small contributory effect of the nutrition of chickens. This theory has now been reversed with much evidence pointing towards NSP causing anti-nutritive effects at levels as low as <50 g/kg in broiler diets. (Choct & Annison 1992)

The anti-nutritive effects caused by nsp's were first noted in barley and rye based poultry diets (Antoniou and Marquardt 1981, Ward and Marquardt 1987). Wheat does not have such high levels of nsp's as does barley and rye but they are still present in enough quantity to have an anti-nutritive effect. Mollah *et al* (1983) and Rogel *et al* (1987) found that some Australian wheats had low levels of AME when fed as broiler diets. These were linked to the level of nsp in the wheat because of the similarities found with feeding rye based diets.

NSP's can not be directly digested by enzymes present in the digestive tract and are fermented in the hind gut by microflora producing volatile fatty

acids and gases. (Adams & Pugh 1993). Only the water soluble fraction can be digested by the chicken, the water insoluble fraction remains un-digested. The result can be increased gut digesta viscosity, a reduced growth rate and increased health problems (Adams & Pugh 1993, Choct and Annison 1992). It is not understood completely how this anti-nutritive effect works, one suggestion is that the increase in viscosity decreases the rate of diffusion and interferes with interaction between the substrates and enzymes. (Edwards *et al.*, 1988, Ikegami *et al.*, 1990). There may also be direct complexing between enzymes and pentosans. (Ikeda & Kusano, 1983). Campbell *et al.* in 1983 concluded that nsp either increased the gut digesta viscosity or increased the stimulation of gut microflora, which utilised the energy rather than allowing absorption of nutrients.

2.4.5. Crude Protein.

Though the protein in the wheat is of secondary importance to the energy, it can and does supply a significant amount, about 35% (McNab 1991) of protein in poultry diets. The amount of protein is very variable between wheat samples and can range from 9% to 15% (Wiseman, 1990). However, this is not usually so much down to the variety as it is to climate and

husbandry effects. These factors are thought to have four times as much effect as that of the variety. (Fenwick, 1990). A high protein content in feed wheat is an added advantage in that it saves on having to source the protein from elsewhere, thus saving costs.

2.4.6. Amino Acids

Though the protein value of wheat for poultry diets is of importance, it is more the proportion of the essential amino acids, those that can not be synthesized and are required in the diet, that are important. (Wiseman, 1990).

The most important amino acids for poultry nutrition are methionine, lysine and cystine. However, cereal proteins are deficient in some essential amino acids, notably lysine and methionine. Wheat ranks below oats and barley in terms of essential amino acid supply, mainly because it has a lower level of lysine. (Macdonald *et al.*, 1988). About 25% of total dietary requirement of lysine, can be supplied by wheat and this figure can be potentially higher if the protein content is higher. (Wiseman and Inborr, 1990).

2.4.6. Vitamins and Minerals.

Though wheat is not thought of as an important source for microelements, it does supply some vitamins and minerals. (Wiseman and Imborr, 1990). However, the cereals are all deficient in calcium, (< 1 g/kg DM) Much of the phosphorus (3 - 5 g/kg DM) is in the form of phytic acid, in the aleurone layer. Also deficient are vitamin D, riboflavin and provitamin A, but vitamin E content is good as well as that of thiamin. (MacDonald *et al.*, 1988).

Table 2.5 Protein Content % at 14% DM Feed Wheat Varieties.

(NIAB, from Fenwick, 1990)

Variety	Mean Protein Content % at 14%DM
Dean	10.9
Galahad	10.8
Apollo	10.8
Haven	10.7
Brock	10.6
Slejpner	10.5
Hornet	10.4
Beaver	10.4
Riband	10.1

(Fenwick 1990. Aspects of Applied Biology 25. Cereal Quality II)

2.5. Measures of Wheat Milling Quality.

2.5.1. Hagberg Falling Number.

The Hagberg Falling Number test is used as a quality measurement of alpha-amylase activity in the grain. (Fenwick, 1990). Alpha-amylase is an enzyme that causes the hydrolysis of the starch to provide energy once germination is under way. The enzyme can be present in the grain without visible signs of sprouting, and some varieties can have high levels of alpha-amylase without germination activity. (Fenwick, 1990). In brief the procedure is that the wheat flour is mixed with water and heated then the time taken for a plunger to pass through the mixture is measured. A high Hagberg falling number is a sign of low alpha amylase activity and of high quality.

Hagberg falling number is of most importance to the bread making industry, but a good value is also beneficial in a feed wheat in terms of quality.

2.5.2.Specific Weight.

The specific weight measurement is a very old test that dates back to when grain was brought and sold purely by weight and appearance. It is simply the weight of a specific volume of grains and a higher figure is indicative of plump, clean well formed grains. Standards for feed wheat are lower than those for milling wheat, being around a minimum of 68 kg/hl (Fenwick, 1990). Again a high specific weight will indicate a higher quality feed wheat in that the ratio of starch to cell wall components, such as non-starch polysaccharides, will be high.

2.5.3. Endosperm Hardness

The hardness measurement of the wheat grain is used as a measure of the samples quality for milling. Hard wheats tend to mill better than soft wheats. A hard wheat has the characteristics of shattering when being ground giving a smooth, regular flour. A soft wheat will tend to smear under grinding giving a poor quality uneven flour. (Pomeranz, 1988).

The hardness characteristic is thought to be due to the interface between the

starch and protein in the grain, known as the starch/protein matrix. Hard wheats tend to have a regular strong starch/protein matrix with the opposite being found in soft wheats. (Sulaiman *et al.* 1993).

It is thought that the formation of this matrix is a combination of the wheat genotype and the specific environmental conditions during the development of the wheat grain.. As a result even if the wheat variety in question has a genetic tendancy for hardness, this will only occur if the environmental conditions allow the protein content to be at a high enough level to form the matrix. Wet weather at harvest can lead to a reduction in the hardness of wheat (Wiseman & Inborr, 1990).

Hardness has also been linked to pentosans, in that branching in pentosans increases with the hardness of the wheat. An interaction between hardness and pentosans has also been shown by low levels of pentosans combined with a reduction of grain hardness, as a result of cool, damp conditions.

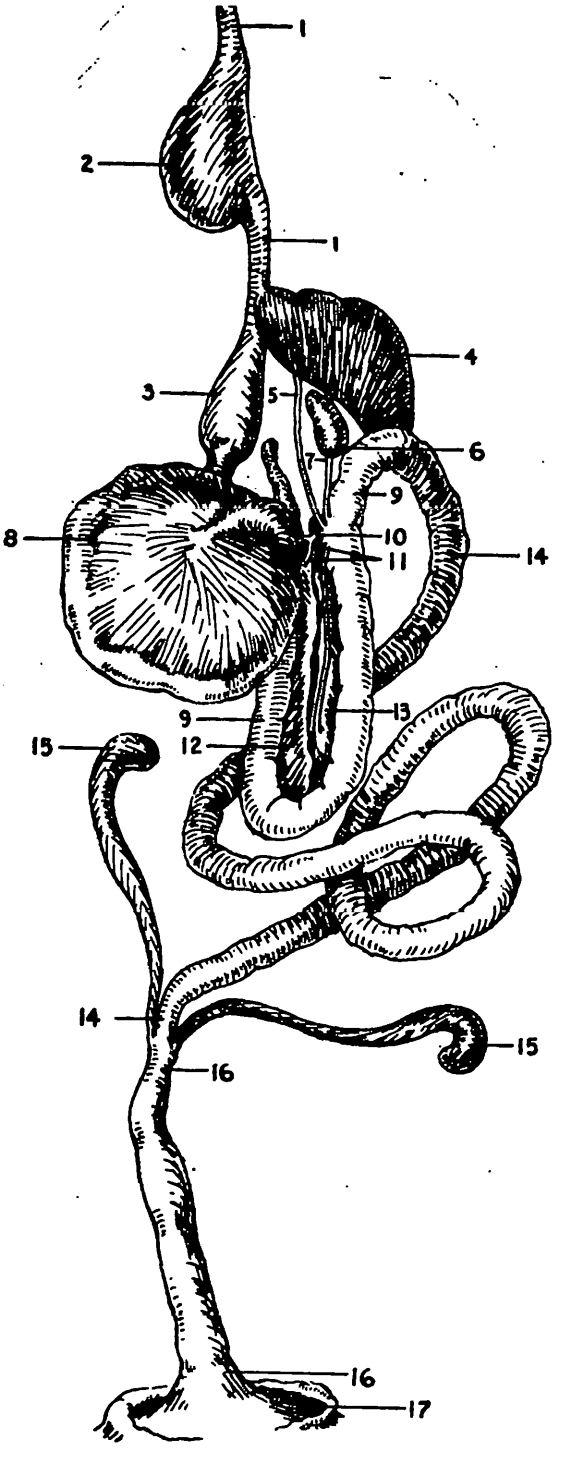
2.6. The Digestive Tract of the Chicken.

The process of digestion and absorption of the energy and other nutriitonal qualities of the wheat in the digestive tract may explain some of the differences between wheat samples in terms of overall production.

2.6.1. The Mouth

The mouth of the chicken is enclosed by the har upper and lower mandibles, forming the beak. The tongue helps to force food into the oesophagus by its rough surface. The food passes quickly through the mouth, no cheweing or digestion taking place. However, there is some secretion of saliva from branched tubular cells amongst the stratified squamous epithelium lining the cavity. Though this saliva does contain amylase, there is little time for it to have any effect, other than to serve as a lubricant. (Sturkie, 1965, Rose 1997, North 1984)

Fig 2.3 The Digestive Tract of The Chicken.



1. Oesophagus, 2. Crop, 3. Proventriculus, 4. Liver, 5. Hepatic duct, 6. Gall bladder, 7. Cystic duct, 8. Gizzard, 9. Duodenum, 10 and 11. Pancreatic ducts, 12 and 13. Pancreas, 14. Small intestine, 15. Caeca, 16. Rectum, 17. Cloaca

2.6.2. Oesophagus and Crop.

In the adult bird the length of the oesophagus varies between 6 to 8 inches. (Sturkie, 1964). The crop is an extension of the oesophagus, that is distendable, allowing the storage of feed when the digestive tract is already full. Again there is some saliva secretion, but little digestion takes place. (North, 1984). There is a bacterial prescence in the crop, mainly *Lactobacillus*, that cause some fermentation of carbohydrate for their own use, a by-product of this is lactic acid, causing the pH of the crop contents to decrease over time of storage. (Rose, 1997).

2.6.3. Proventriculus and Gizzard

The proventriculus is also known as the glandular, or true stomach. (North, 1984). This is due to the prescence of gastric glands lining the membrane, producing gastric juice, producing both hydrochloric acid and pepsinogen. The reduction of pH allows the formation of pepsin, leading to some protein hydrolyis. (Rose, 1997). In the chicken the proventriculus is relatively small and therefore the food passes through quickly, allowing little time for

serious digestion to occur. The digesta is however now in a state where digestion can take place, which begins in earnest in the gizzard.

The gizzard is a powerful muscular stomach, which grinds up large particles of feed, for example whole wheat grains can be ground by the contractions of the gizzard walls and it is the prescence of this organ that allows wheat to be fed as whole grains. The muscular wall of the gizzard is protected by koilin, a protein-polysaccharide substance, which forms a mesh. (Rose, 1997). Grinding of the feed is aided by the prescence of gritty granules and the amount of time feed remains in the gizzard can depend on its coarseness. (North, 1984).

2.6.4. The Small Intestine.

The small intestine comprises three parts, the duodenum, jejunum and the ileum. In total the small intestine will measure, on average, 1.5 metres in an adult bird. (North, 1984). This is relatively short and the passage of food through the small intestine is quick, though the chicken does have the capability of reverse peristalsis in the duodenum, thus increasing the time for digestion and absorption of nutrients. (Rose, 1997). The mucosal lining of the small intestine secretes gastric juice containing digestive enzymes and bile and pancreatic enzymes are secreted into the duodenum.

2.6.5. The Large Intestine

The chicken has a relatively short large intestine, only 10 cm long in the adult bird. (North, 1984). The usual functions of water reabsorption takes place in the large intestine. The chicken does posses two large ceaca which vary in size from 5 cm in the young bird to 17 cm in the adult bird. (Sturkie, 1964). The ceaca contain a large poulation of bacterial organisms, the gut microflora, which live off digesta that has past through the small intestine without being fully digested. Short chain fatty acids are produced as by-products of this fermentation and these can be absorbed into the blood stream, though there is thought to be little overall contribution in nutritional terms.. (Rose, 1997). Much of the digesta that reaches the ceaca will be that which the chicken can not digest easily, namely the dietary fibre or the non-starch polysaccahrides. High viscosity has also been shown to decrease the speed of digesta passage and as a result increase the microbial population of the intestine having a negative effect on the bird. (Classen & Bedford, 1991).

2.7. Conclusion

Wheat is a major provider of energy and protein in broiler chicken feeds in the UK and other Northern European countries. There is evidence that the growth and feed conversion ratios of broilers vary due to the type of wheat sample that is provided in the diets. There is further evidence that variety differences have consistent effects on the growth performance of broilers.

Wheat is a major provider of available energy in broiler feeds. The energy availability of wheat is often measured as metabolizable energy. However, there is a poor relationship between the determined metabolizable energy of a wheat sample and the resulting broiler growth and feed conversion ratio when it is fed to broiler chickens. Metabolizable energy determination may not detect differences between wheat samples in their net energy availability. A number of factors may be involved, however differences in the amount of non-starch polysaccharide fermentation in the distal parts of the digestive tract may cause differences in the apparent utilization of energy. There is a need to examine whether there are differences between wheat samples in the net energy retention of broiler chickens and examine whether these differences are correlated to any chemical or physical

differences between wheat samples.

3.0 MATERIALS AND METHODS.

3.1. Wheat Samples

Eighteen wheat samples were used in the trial, comprising six varieties of wheat. The varieties were as follows: Dean; Beaver; Haven; Riband; Rialto; Brigadier. They were all grown in a replicated random block design in one field, at Harper Adams, in the harvest year of 1994. Each variety was grown in three blocks giving three samples per variety, making a total of eighteen samples.

3.2. Diets.

The diet for the trial was formulated with the aim of providing the highest inclusion of wheat possible, within a nutritionally adequate broiler diet. This was to ensure that the maximum effects of the wheat variety would be evident, it also reflects general commercial practice where wheat is generally included in broiler diets at the highest level as possible. Wheat is currently the lowest cost source of energy available in the UK and in a number of other northern European countries. As the wheat is the major

supply for energy and a significant provider of protein, it can be included in the diet at up to 65%.

The diet was formulated to provide all the required protein, nutrients and minerals required by the chicken and to provide around 13 MJ/kg of energy, which is about the amount required for broiler production. (see table 3.2)

The wheat samples were then mixed in 18 experimental diets, one for each wheat sample, using a Gardner 25 kg mixer. The samples were then put through a Philco Dierings pelleter. The pelleter was thoroughly flushed through with a standard sample in order to prevent any possible contamination between the samples. The diets were pelleted to reflect current commercial practice and to provide the best available form of the feed to the chickens.

Table 3.1 The Ingredients and nutrient composition of the trial diet

Feed ingredient	**Amount (g/kg)**
Wheat	650
Soya bean meal	40
Full fat soya	140
Fish meal	110
Meat & bone meal	25
Dicalcium phosphate	15
Vitamins & minerals[1]	20
Nutrient composition	
ME (MJ/kg)	12.50
Crude protein (g/kg)	226
Lysine (g/kg)	13.0
Methionine plus cystine (g/kg)	7.5
Tryptophan (g/kg)	2.5
Calcium (g/kg)	15.3
Phosphorus (g/kg)	10.1
Sodium (g/kg)	3.0

1. The proprietary supplement was supplied by Ian Hollows Feed Supplements Ltd., Whitchurch, UK. It provided the following nutrients (mg/kg of supplement): 38.4 retinol, 0.6 cholecalciferol, 2000 a-tocopherol acetate, 240 thiamin, 800 niacicn, 1200 pantothenic acid, 240 pyridoxine, 1.2 cyanocobolamin, 20,000 choline chloride, 10 biotin, 120 folic acid, 1600 iron, 80 copper, 8000 manganese, 6400 zinc, 80 iodine and 16 selenium.

3.3. Proximate Analysis.

Laboratory tests were carried out on the wheat, diet, excreta and body tissue samples. The wheat and diet samples were all milled in a Hagberg Falling Number Laboratory Mill 3100 prior to all analysis. All analysis was carried out in triplicate.

3.3.1.Crude Protein.

Determination of the crude protein was performed on the wheat samples, the diets and excreta samples. The Kjeldahl technique measures the nitrogen content of the sample, from which the protein content can be calculated. The term crude protein is used because a number of assumptions are made with this system. Firstly, the assumption that all nitrogen in the sample is protein, whereas in many feeds there is up to 5% in compounds such as amides and in root crops this figure can be much higher. Secondly, the assumption is made that all the protein in a feed contains 16% nitrogen, whereas in reality it varies between 15 - 18%.

The analysis was made using a Tecator Kjeldahl Auto Analyser. An accurately weighed 1 g sample was enclosed in an ashless filter paper envelope. The envelope was then placed in a Kjeltec tube with 2 Kjeltabs, (catalyst), in each tube. To each tube 14 ml of concentrated H_2SO_4 was added in a fume cupboard. The rack of 24 tubes was then placed on a pre-heated digestion block, at 410°C, in a fume cupboard with a scrubber unit placed on the tubes. The tubes were left on the block for at least 45 min, until the liquid has turned green. After cooling the tubes for about 15 min 75 ml of distilled water was added. The rack of tubes was then placed on the Kjeldahl autoanalyser for analysis to take place.

3.3.2.Ether Extract.

The ether extract fraction of a wheat or feed sample is that which is fat, oil or wax. The method uses petroleum spirit to extract the fraction. Both wheat samples and diet samples were analysed for ether extract. The weights of the empty sample thimble and support were recorded. Between 2 and 3 g of sample was then placed in each thimble and the weights recorded. Each thimble was then plugged with defatted cotton wool, using forceps to ensure that no oil contamination occurred. The extraction cup weights were also

recorded. The extraction cups were then placed in the fume cupboard and 25 ml of 35 - 60 petroleum ether (Sigma Aldrich Ltd, no: 18451-9 Dorset). The thimbles and extraction cups were then placed on to the Tecator Soxtec System HT 1043 Extraction Unit and boiled for 15mins, followed by 10 mins rinsing. The remaining solvent in the extraction cups was evaporated off leaving the fat.

3.3.3. Dry Matter.

All wheat, diet, excreta and carcass samples were fully dried in order to perform proximate analysis, to accurately adjust and represent values and to enable milling. Different methods of drying were used for the samples due to physical properties and moisture contents.

The wheat samples were milled and then placed overnight in a fan assisted oven at approximately 100°C. A weigh back was then made to ensure that all moisture had been dried off and the dry matter recorded. The same process was repeated with the diet samples.

Due to the high moisture content in the excreta these samples had to be

dried in a fan assisted oven at 60°C for four days. Again weigh back checks were made to ensure that all moisture had been removed. The samples were then milled using a Tecator Cyclotec 109S Sample Mill.

An alternative system had to be found to dry the carcass samples as oven drying is obviously not possible. The samples were covered with pierced tin foil and placed in an Edwards Modulyo Pirani 501 Freeze Dryer at 20 mbar and minus 50°C for six days. Once weight checks had been carried out, the samples were then ground up using a hand held electric coffee grinder. It was not possible to use a conventional mill for this due to the fat contained in the sample.

3.3.4.Ash

The determination of ash is used to find the mineral component of the sample. This analysis was performed on the wheat samples. About 4 g of sample was placed into a pre-weighed porcelain crucible and re-weighed. The crucible was then placed into a Gallenkamp Muffle Furnace and heated at between 450°C and 500°C overnight. The crucibles were then placed in a dessicator to cool, before being weighed to determine the percentage of ash.

3.3.5. Neutral Detergent Fibre

The neutral detergent fibre content is the indigestible fibre left after the starch is removed.

The wheat samples were analysed for neutral detergent fibre as follows. Approximately 0.5g of milled wheat sample was placed into a previously weighed crucible, which was then placed in the Tecator Fibertec System 1020 Hot Extractor. Twenty five ml of cold neutral detergent reagent and 0.5 ml octanol was added and then boiled and digested for 30 mins. The

heat was then turned off and the samples mixed. Another 25 ml of cold neutral detergent reagent was added with 2 ml of alpha amylase. This was then boiled and digested for 30 mins. The digest was then filtered and washed three times with 20 ml of hot distilled water (80°C), ensuring the removal of all the reagent. Following filtration, 25 ml of hot distilled water and 2 ml of alpha-amylase was added and the sample mixed and left to stand for 15 mins. The samples were then filtered and washed three times with hot distilled water and once with 20 ml acetone. The crucibles were then removed from the apparatus and dried overnight at 100°C, cooled in a dessicator, then weighed. The samples were then put into the muffle furnace at 500°C overnight, cooled in a dessicator and weighed.

3.3.6.Gross Energy

All gross energy analysis was carried out using an adiabatic bomb calorimeter. Wheat, diet, excreta and carcass samples were all analysed for gross energy. The dried, milled and homogenised wheat, diet and excreta samples were analysed using standard techniques of weighing out a known amount of sample which was then put into the bomb calorimeter. The calorimeter was standardised using sucrose for these samples and benzoic

acid for the carcasses. The freeze dried carcass samples had to be treated differently as they could not be milled using a coventional mill. Each sample was mixed and then ground using a small Kenwood coffee mill. This produced a fine enough sample for analysis yet did not get clogged with sample. From the milled sample, four pellets were made using a hand pelleter. Three pellets were analysed for gross energy to give a good replication, the fourth being used as a spare if needed as a further replicate.

3.3.7.Non-Starch Polysaccharides

The wheat samples were analysed for non-starch polysaccharides, NSP, or dietary fibre. The importance of NSP's has been discussed elsewhere and the procedure alone is dealt with here. The method used was one developed by Englyst (1989), which is cheaper and simpler than the alternative gas-liquid chromatography method and almost as accurate.

The basic principles behind the procedure involves the gelatinization of the starch which is then removed by enzymatic digestion. The NSP are hydrolysed with sulphuric acid which releases neutral sugars and uronic acids that are then measured by colorimetry.

Two duplicate sets of sample were weighed, (300 mg to nearest 0.1 mg), in to 50 ml screw top glass tubes. To each tube was added 300 mg (+/- 20 mg) of acid washed sand and approximately 15 glass balls. Two ml of Dimethyl sulphoxide, (DMSO),was added to the tubes which were then vortex mixed 3 to 4 times in 5 mins. The tubes were then placed in a boiling water bath two at a time. After 20 seconds the tubes were removed and vortex mixed again and two more tubes placed in the water bath. Once all the tubes had been mixed they were left in the boiling bath for 30 minutes. During the 30 minutes two enzyme solutions were made up. Enzyme solution one was made with 2.5 ml heat stable amylase which was made up to 200 ml with sodium acetate buffer. Enzyme solution two with 1.2 g of pancreatin added to 12 ml water which was mixed and centrifuged. Then 10 ml of the supernatant was added to 2.5 ml of de-branching enzyme. One tube was removed at a time and 8 ml of enzyme solution one added. The tubes were mixed, then replaced in the boiling bath for 10 minutes. They were then transferred to a 50°C water bath for 3 minutes, after which 0.5 ml of enzyme solution two was added, the tubes mixed and replaced in the 50°C bath for 30 minutes. The tubes were then transferred to the boiling bath for 10 minutes.

At this point the samples were divided into two. This was in order to calculate the levels of both water soluble NSP and water insoluble NSP. The following part of the procedure refers to the water insoluble batch.

The samples were cooled in ice water and 0.15 ml of 5M Hydrochloric acid and 40 ml of acidified (I ml of 5M Hydrochloric acid per litre ethanol), absolute ethanol added. The samples were left in ice water for 30 mins. The tubes were then centrifuged at 1500 g for 10 minutes to obtain a clear supernatant which was then removed leaving the residue. Fifty ml of 85% acidified ethanol was added and the centrifuge process repeated. This was then repeated with 50 ml absolute ethanol and again with 30 ml of acetone.

To the other batch, for water soluble NSP, 40 ml sodium phosphate buffer was added. The tubes were then placed in the boiling water bath for 30 mins. They were then centrifuged as described above. This was repeated using 50 ml distilled water, 50 ml absolute ethanol and 30 ml acetone.

All tubes were then placed in a water bath at 75°C in a fume cupboard until the residue looked dry, when they were transferred to a fan assisted oven at 80°C for 10 minutes, to remove all traces of acetone. To each tube was

added 5 ml of 12M sulphuric acid, they were then mixed and placed in a water bath at 35°C for 30 minutes. After this 25 ml of distilled water was added to each tube, the tubes were then placed in a boiling water bath for one hour, and then cooled in tap water.

The samples were then prepared for reading on the Beckman DU 640 Spectrophotometer. Standards were made by taking 0.5 ml stock sugar mixture, (enzyme kit), and 2.5 ml of 2.4M sulphuric acid in to a glass tube. From this two lots of 0.5 ml was pipetted into two glass test tubes. Into each of 24 similar tubes 0.5 ml of each hydrolysate, (duplicated), was pipetted. Two tubes had 0.5 ml of the blanks, which was 2M sulphuric acid. To each tube 0.5 ml of Dimethyl Glutaric Acid Solution, (DMG), was added. The tubes were placed in a water bath at 50°C for 20 mins and then cooled. Then 0.1 ml of 3M sodium hydroxide and 1 ml of the kit colour reagent were added and the tubes placed in a boiling water bath for 5 minutes. They were then cooled, 10 ml of distilled water added and measured at 530 nm on the spectrophotometer.

3.4. Summary of Chemical Analysis Performed.

a) Crude protein using Kjeldahl auto tecator.

b) Ether extracts using soxtec analyser.

c) Dry matter and ash.

d) Gross energy using adiabatic oxygen bomb calorimeter.

The following analysis was performed on the wheat samples.

a) Hagberg falling number.

b) Hardness.

c) Specific weight.

d) Starch analysis: Soluble and non-soluble non-starch polysaccharides.

e) Neutral detergent fibre using fibertec equipment.

The folowing analysis was performed on the excreta samples.

a) Dry matter and ash.

b) Gross energy using adiabatic oxygen bomb calorimeter.

The following analysis was performed on the body samples.

a) Gross energy using adiabatic oxygen bomb calorimeter.

b) Protein

c) Fat (extractable).

d) Dry matter and ash.

3.5. Experimental Design.

Ninety six seven day old male Ross chicks were selected randomly from the main broiler flock. They were then allocated, two birds per cage, to forty eight cages arranged in two blocks of twenty four cages. Each cage had a floor area of $0.1m^2$. This provided four replicates for each diet. The cages were arranged in two blocks of twenty four, standing back to back. The block design was arranged so that one block consisted of the upper twelve cages of both sides and the other block of the lower twelve cages of both sides. This was to reduce any possible variation caused by the cage position on the birds' growth. Another six chicks were randomly selected, killed by cervical dislocation, then frozen at - 20°C to provide a mean measure of the starting net energy content of the birds at seven days.

The chicks were randomly allocated to a cage in each block and were then allowed access to feed and water ad lib from 7 to 21 days. Feed intake and broiler weight gain was recorded over the experimental period (14 days). During the last four days of the trial the excreta was collected and air dried in a fan oven at 60°C for forty eight hours. It was then weighed and milled, using a Tecator Cyclotec 109S Sample Mill, for AME analysis. The feed

intake during this period was also measured. At 21 days the birds were weighed and killed by cervical dislocation. The contents of the digestive tract, from the duodenal loop to the Merckles' diverticulum, were collected, centrifuged and analysed for viscosity using a Brookfield digital viscometer, Model DV - II+ Version 3.0. Each bird was frozen whole, at minus 20°C, for storage.

To determine the energy content of the bird carcass, a system had to be developed that provided a representative sample that could be analysed for net energy using the oxygen bomb calorimeter. To provide a fine enough sample the whole bird carcass was thawed, then put through a Crypto Peerless TC32 mincing machine. The minced carcass was thoroughly amalgamated in order to provide a representative sample of the whole bird and avoid over representation of one part of the bird, which may have higher or lower levels of energy than the mean for the whole carcass. About 100 g of the minced carcass was then stored at minus 20°C until required for analysis. The same process was repeated with the seven day old chicks previously frozen. This was to provide a mean starting net energy level for the purpose of calculating the net energy level of the 21 day old birds. The whole trial was repeated exactly except for changing the allocation of diets

to cages, to give a total of eight birds per diet.

The trial was designed to include another six wheat samples sourced from Szeged, Hungary. This was to examine the possibilities of differences in productive performance between the English and Hungarian wheats. No significant differences were found and the birds fed the Hungarian wheats were not included in the rest of analysis. This explains the number of birds used in the trial, the trial being a 24 treatments x 8 birds giving a total of 192 birds.

3.0 Statistical Analysis

The results of the broiler growth experiment were compared in a randomized block analysis of variance design. A factorial treatment structure was incorporated in which the wheat variety and the crop field trial block were used as main treatment factors and their interactions were examined.

The relationship between the chemical composition of the 18 wheat samples and the growth and feed conversion ratio of broilers fed the wheat samples

were examined by linear regression techniques.

4. Results.

4.1 Chemical and physical composition of the wheat samples.

There were few differences in the proximate nutrient composition of the 18 wheat samples (Table 4.1). The dry matter content only varied between 867 to 874g/kg although the crude protein contents also had a larger range (114 to 160g/kg). The differences in crude protein were mostly related to variety differences. There seemed to be few consistent differences in proximate composition that were related to positional block within the field trial.

The differences between the samples in Hagberg Falling Number, endosperm hardness and specific weight were mostly due to varietal differences (Table 4.2). There were few differences in the total non-starch polysaccharide (NSP) compositions of the wheat samples although the three Samples of variety Riband had low soluble NSPs.

4.2 Broiler Growth Trial

There were no significant differences due to wheat variety or wheat growth block in the weight gains or feed intakes of the broilers (Table 4.3 and 4.5). However, there were significant ($p<0.05$) differences in the feed conversion ratios of the broilers given the different wheat varieties. The birds fed the variety Riband had a low ($p<0.05$) digesta viscosity compared to the other five wheat varieties (Table 4.5).

Table 4.1 Proximate analysis of the 18 wheat samples (g/kg of dry matter, unless stated).

Wheat (plus block no.)	DM	Ash	Gross Energy MJ/kg	Ether Extract	Neutral Detergent Fibre	Crude Protein
Dean 1	868	19	18.72	13.1	178.3	144.0
Dean 2	873	16	18.81	13.4	126.9	114.6
Dean 3	869	14	18.82	12.9	163.6	149.6
Brig 1	872	16	18.85	14.7	131.4	144.5
Brig 2	874	15	18.28	14.4	104.0	153.3
Brig 3	873	16	18.76	14.7	154.1	139.8
Beaver 1	869	20	18.73	14.0	157.5	139.2
Beaver 2	872	17	18.57	15.4	211.4	144.5
Beaver 3	874	18	18.84	14.6	136.8	157.9
Rialto 1	872	16	19.09	15.8	202.4	160.6
Rialto 2	874	16	18.80	15.3	165.1	143.0
Rialto 3	872	16	18.89	15.5	173.9	147.9
Riband 1	872	16	18.80	18.3	195.2	135.3
Riband 2	867	13	18.66	16.8	119.6	131.5
Riband 3	873	14	18.76	16.8	182.9	138.6
Haven 1	867	15	19.03	16.5	196.3	149.9
Haven 2	869	14	18.70	16.0	148.2	134.6
Haven 3	876	14	18.75	16.8	177.1	132.4

Table 4.2. Chemical and Physical Characteristics of the 18 Wheat Samples. (g/100g dry matter unless stated).

Wheat (block)	Hagberg Falling No. (sec)	Endosperm Hardness % Rel. units	SpecWt kg/hl	NSP (g/100g)	Soluble NSP g/100g	Insoluble NSP (g/100g)
Dean 1	444	94.38	77.3	8.29	2.19	6.10
Dean 2	447	92.48	78.7	9.11	2.26	6.85
Dean 3	428	98.90	77.3	8.87	3.47	5.40
Brig 1	373	83.89	75.7	9.85	2.95	6.90
Brig 2	336	74.28	77.7	9.97	2.56	7.41
Brig 3	432	81.62	77.9	9.98	2.21	7.77
Beaver 1	399	29.87	75.9	9.00	2.10	6.90
Beaver 2	276	33.03	77.1	8.91	3.35	5.56
Beaver 3	290	33.17	76.3	10.40	2.47	7.93
Rialto 1	439	83.20	77.1	9.65	2.19	7.46
Rialto 2	386	86.42	77.7	9.11	2.26	6.85
Rialto 3	383	86.85	77.1	9.80	2.03	7.77
Riband 1	293	50.33	76.1	8.49	1.85	6.64
Riband 2	296	70.50	77.1	8.51	1.64	6.87
Riband 3	284	55.90	77.5	8.76	1.69	7.07
Haven 1	412	46.90	76.7	9.44	2.68	6.76
Haven 2	380	55.57	77.3	8.88	2.29	6.59
Haven 3	407	36.77	78.1	8.93	2.25	6.68

Table 4.3: Weight Gain, Feed Intake, Feed Conversion Ratio and Digesta Viscosity of Broiler Chickens given diets containing the 18 Wheat Samples, from 7 to 21 days.

Wheat (block)	Weight Gain (g/bird)	Total Intake (g/bird)	F.C.R. (g per g)	Digesta Viscosity (cp)
Dean 1	739	1330	1.799	14.19
Dean 2	744	1262	1.696	14.19
Dean 3	745	1203	1.615	21.94
Brigadier 1	690	1244	1.803	18.52
Brigadier 2	724	1232	1.702	18.20
Brigadier 3	621	1005	1.618	16.58
Beaver 1	662	1147	1.733	22.86
Beaver 2	765	1256	1.642	24.79
Beaver 3	722	1289	1.785	16.04
Rialto 1	654	1177	1.800	20.88
Rialto 2	634	1134	1.789	17.69
Rialto 3	672	1283	1.909	21.52
Riband 1	712	1226	1.722	8.33
Riband 2	623	1205	1.934	13.50
Riband 3	664	1173	1.767	9.62
Haven 1	644	1094	1.699	19.43
Haven 2	732	1234	1.686	22.63
Haven 3	741	1282	1.730	22.39
SEM	39.8	660	0.0621	3.863

Table 4.4. AME and Energy Retention and Energy Retention per unit of Metabolisable Energy eaten For Diets Containing 18 Wheat Samples.

Wheat (block)	AME MJ/kg	Energy Retention (MJ/kg)	Energy Retention per ME intake MJ/MJ
Dean 1	15.41	8.67	0.423
Dean 2	15.68	8.76	0.443
Dean 3	15.93	8.68	0.453
Brigadier 1	15.34	7.82	0.410
Brigadier 2	15.19	8.76	0.468
Brigadier 3	15.67	7.11	0.452
Beaver 1	15.42	7.74	0.438
Beaver 2	15.87	8.38	0.420
Beaver 3	15.57	8.19	0.408
Rialto 1	15.44	7.39	0.407
Rialto 2	15.22	6.86	0.396
Rialto 3	15.50	7.60	0.382
Riband 1	15.49	7.90	0.416
Riband 2	14.64	7.30	0.414
Riband 3	15.93	7.50	0.399
Haven 1	15.57	8.35	0.490
Haven 2	15.78	8.10	0.416
Haven 3	15.83	8.50	0.419

Table 4.5. The Effect of Diets Containing Six Different Wheat Varieties on the Weight Gains, Total Feed Intakes, Feed Conversion Ratios and Digesta Viscosities of Broiler Chickens.

	Wt gain (g per bird)	Total intake (g per bird)	F.C.R. (g per g)	Digesta viscosity (cp)
Effect of variety	NS[1]	NS	*[2]	*
Dean	743	1265	1.703	16.77
Brig	678	1160	1.711	17.77
Beaver	716	1231	1.719	21.23
Rialto	653	1198	1.835	20.03
Riband	666	1201	1.803	10.48
Haven	706	1203	1.704	21.48
SEM	20.76	33.8	0.0375	2.386
Residual (df)	49	49	49	44
Effect of growing block	NS	NS	NS	NS
Block 1	683	1203	1.761	17.43
Block 2	712	1233	1.732	18.06
Block 3	694	1228	1.769	18.27
SEM	14.68	23.9	0.0265	1.687
Residual df	49	49	49	44

1. NS = ($P > 0.05$)
2. * = ($P < 0.05$)

There were no significant ($p>0.05$) differences in the determined apparent metabolizable energy concentrations of the diets (Table 4.6). However, there were large differences ($p<0.01$) in the total energy retentions of the broilers fed different wheat varieties. These differences continued to be evident ($p<0.01$) even when the energy retention was expressed per MJ of AME intake of the individual cages of broilers.

4.3 Relationship between chemical and physical characteristics and broiler growth and feed conversion ratios.

The weight gains of the broiler chickens fed the 18 different wheat samples were significantly negatively related ($p<0.05$) to the soluble non-starch polysaccharide (NSP) content of the wheat samples (Table 4.7 and 4.8), particularly the soluble NSP content (Figure 4.1). The feed conversion ratio of the broilers was significantly ($p<0.05$) related to the determined AME of the diets but this may have been attributable to one outlying value (Figure 4.2).

There were no significant relationships ($p>0.05$) between the energy retention per MJ of AME intake and any chemical or physical characteristic of the wheat samples .

Table 4.6. The Effect of Six Different Wheat Varieties on the AME, ER (Energy Retention) and ER per ME Determined in Nutritionally Complete Diets Given to Broiler Chickens.

WHEAT	AME (MJ/kg)	ER (MJ)	ER per ME (MJ per MJ)
EFFECT OF VARIETY	NS[1]	**[2]	**[2]
DEAN	15.69	8.72	0.510
BRIGADIER	15.32	7.90	0.500
BEAVER	15.70	8.10	0.489
RIALTO	15.42	7.36	0.458
RIBAND	15.42	7.70	0.482
HAVEN	15.76	8.46	0.496
SEM	0.1949	0.2362	0.00949
Residual df	48	48	48

1. NS = ($P > 0.05$)
2. ** = ($P < 0.01$)

Table 4.7. Correlation Matrix: Wheat Chemical/Structural Composition Correlation to Productive Performance Factors: Weight Gain, Feed Intake, Feed Conversion Ratio, and Viscosity.

	Prot	EE	GE	HFN	SWt	Hd	WG	TI	FCR	Visc
Prot	1.0000									
EE	-0.1034	1.0000								
GE	**0.7608**	0.1509	1.0000							
HFN	**0.5212**	**-0.5147**	0.3939	1.0000						
SWt	-0.0129	-0.1745	-0.2349	0.3379	1.0000					
Hd	0.1732	-0.4613	0.1190	**0.5307**	0.3569	1.0000				
WG	0.0384	-0.2830	-0.4005	-0.1103	0.1811	-0.0968	1.0000			
TI	0.0915	-0.1884	-0.2890	-0.1547	0.0930	0.1079	**0.6975**	1.0000		
FCR	0.0522	0.1796	0.2235	-0.0242	-0.1307	0.2667	**-0.6110**	0.1398	1.0000	
Visc	0.3666	-0.2921	0.0111	0.3155	-0.0281	-0.1595	0.1742	-0.0511	-0.2840	1.0000

Notes to Table 4.7

Figures in **bold** are statistically significant ($p < 0.05$)

Prot:	Protein
EE:	Ether Extract
GE:	Gross Energy
HFN:	Hagberg Falling Number
SWt:	Specific Weight
Hd:	Hardness
WG:	Weight Gain
TI:	Total Intake
FCR:	Feed Conversion Ratio
Visc:	Viscosity

4.8. Correlation Matrix: Correlation Between Energy Retention, AME, and NSP and Productive Performance Factors and Viscosity.

	ER	ERME	AME	NSP	SOL	INSOL	WG	TI	FCR	VISC
ER	1.0000									
ERME	**0.4888**	1.0000								
AME	0.3396	0.0695	1.0000							
NSP	-0.1102	0.0994	-0.0279	1.0000						
SOL	-0.4519	-0.1891	-0.2817	**0.7081**	1.0000					
INSOL	**0.4916**	0.3804	0.3554	0.2228	**-0.5306**	1.0000				
WG	**0.8404**	0.0583	0.4753	-0.1912	**-0.5231**	**0.4927**	1.0000			
TI	**0.5628**	-0.4016	0.0162	-0.1852	-0.2205	0.0821	**0.7328**	1.0000		
FCR	-0.4122	**-0.6229**	**-0.6507**	-0.0102	0.3950	**-0.5575**	-0.4004	0.3282	1.0000	
VISC	0.1718	0.1204	0.2119	0.2402	-0.2135	**0.5831**	0.2002	0.0170	-0.2397	1.0000

Notes for Table 4.8

Figures in **bold** are statistically significant ($p < 0.05$)

ER:	Energy Retention
ERME:	Energy Retention per Metabolisable Energy
AME:	Apparent Metabolisable Energy
NSP:	Non-Starch Polysaccharides
SOL:	Soluble Non-Starch Polysaccharides
INSOL:	Insoluble Non-Starch Polysaccharides
WG:	Weight Gain
FI:	Feed Intake
FCR:	Feed Conversion Ratio
VISC:	Viscosity.

Fig. 4.1 Wheat soluble NSP and broiler weight gain.

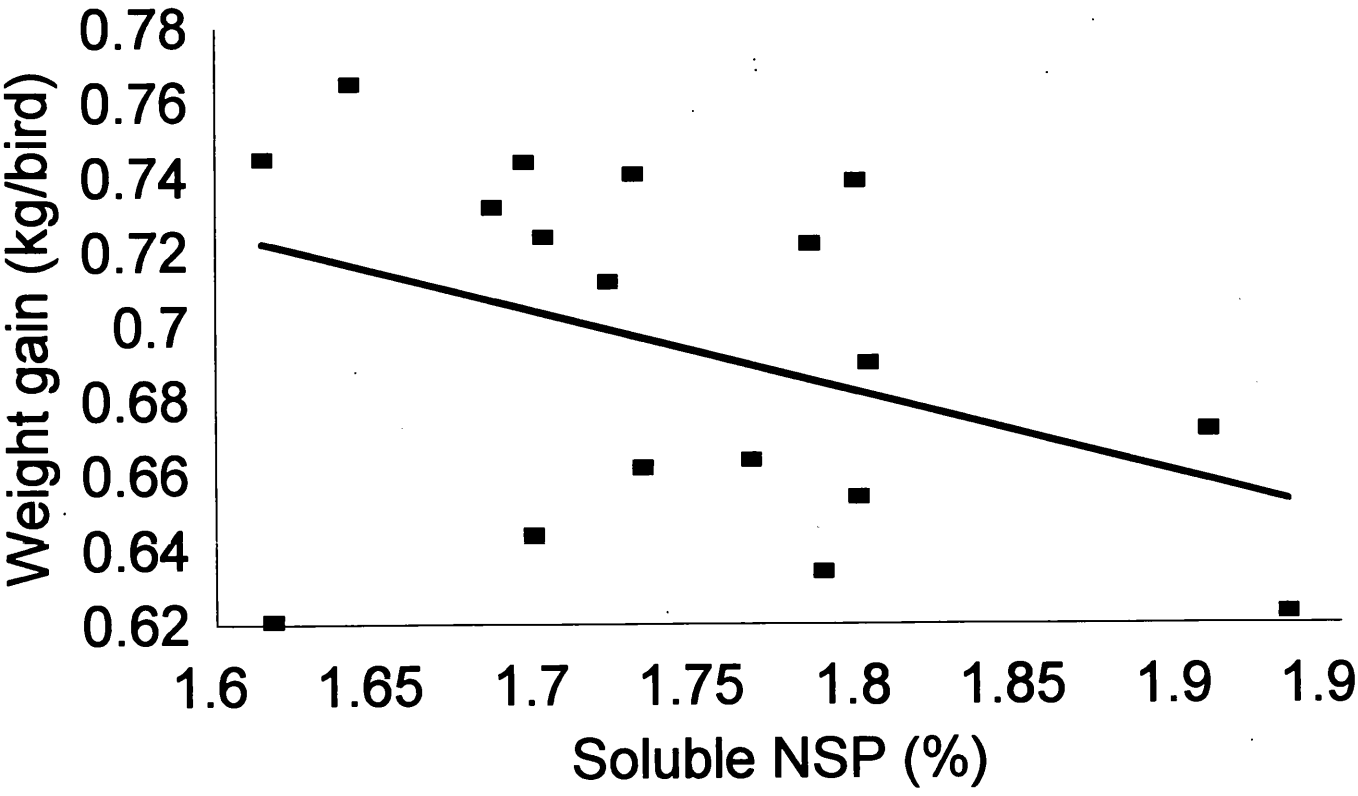
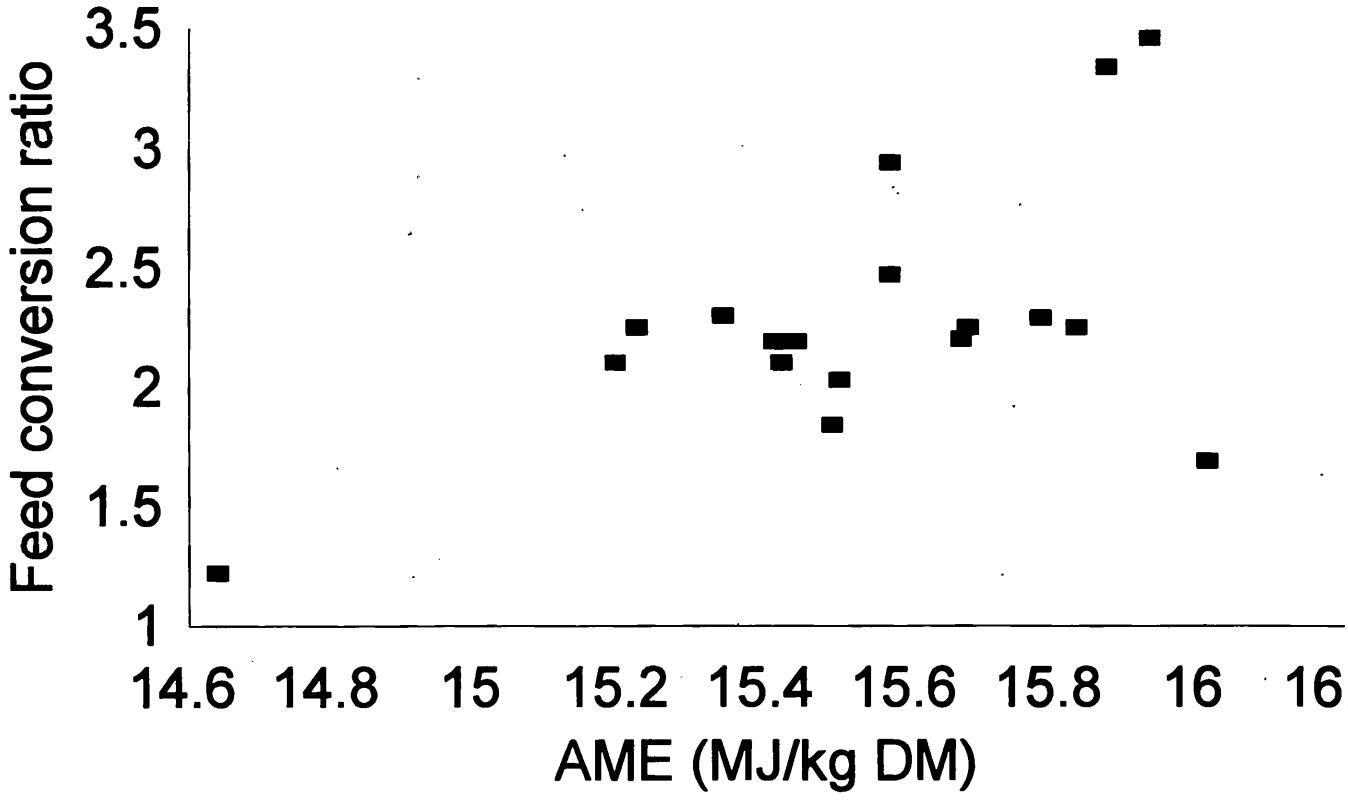


Fig. 4.2 Wheat AME and broiler feed conversion ratio.



5.0 Discussion

The results from the laboratory proximate analysis for the wheat samples are consistant with previously published results on these types of wheat samples. (Waldron *et al* 1993, Rose *et al* 1995). The proximate analysis shows that the wheat samples used were all of a high nutritional standard, having high specific weights and expected crude protein concentrations. The non-starch polysaccharide analysis also revealed generally low levels when compared to some of the high quantities found in, for example, Australian wheat samples. (Choct & Annison 1992, Rogel *et al* 1987). The large ranges that were shown in the Hagberg falling numbers and also in the endosperm hardness can be explained by the varietal characteristics, with some wheat varieties being more suited to bread making. The gross energy concentrations of the wheat were very even throughout all 18 samples with a range of only 0.81 MJ/kg between the lowest and highest.

The lack of significant variety difference in broiler performance are surprising, when previous work by Waldron *et al* (1993) found significant differences between two varieties, Dean and Beaver. It was due to these differences that these two varieties were included in this trial. The difference

between the two samples, apart from harvest year and minor chemical and physical differences, was that the broiler diets were pelleted, whereas those used by Waldron *et al* were fed in meal form. The pelleting process appears to completely reduce the performance differences. This is backed up by later findings by Waldron (1997), who found that the differences observed before were no longer evident if the same samples were fed in diets that had been pelleted.

Feed conversion ratio was found to be significantly different between the broilers fed six different wheat varieties. Out of the six varieties, the birds eating Rialto and Riband had the highest FCR. In the case of the Riband this is particularly unusual because Riband had a low NSP content, especially soluble NSP, which was also reflected in the gut digesta viscosity in that the birds fed the Riband diet were the lowest. Generally it would be thought that this would mean improved bird performance, (Choct *et a*l 1996) yet this was not so in the birds fed the Riband.

A correlation ($P<0.05$) occurred between the feed conversion ratios and the energy retention per MJ of AME intake. There were also relatively large differences in carcass energy retention per MJ of AME intake, that were not

expected. It has been shown that different wheat samples result in different levels of volatile fatty acid production when fed to broiler chickens. (Choct *et al* 1996). The volatile fatty acids are a by-product of bacterial fermentation in the caeca and lower small intestine. The microflora population is thought to increase as a result of an increase in digesta viscosity, which is a result of high NSP's. (Bedford 1996). The different levels of bacterial fermentation of non-starch polysaccharides could explain the lack of correlation between the determined AME of different wheat based diets and the growth and FCR's of Broilers. (Rose & Bedford, 1995). The NSP components of the diet would be expected to act as a substrate to the microbial population of the lower parts of the digestive tract. However, the differences in energy retention were not ($P>0.05$) correlated with the wheat NSP contents.

The results of this experiment show that the measuring of the efficiency of energy retention in broilers could be used as a method for selecting different wheat samples for broiler feeding. There may, however, be a problem with this experiment in the way that the birds were fed. The birds were allowed to feed *ad libitum* and so it is impossible to distinguish whether differences in the efficiency of energy retention were due to a true difference in net

energy concentration or due only to the differences in voluntary feed intakes between the groups.

The chemical and physical characteristics of the wheat samples and the growth, feed conversion ratios and energy retentions of the broilers were not ($p>0.05$) affected by the crop trial positional blocks. Environmental and climate differences during crop growth are known to affect the chemical composition of wheat (Pomeranz 1988). However, the positional blocks in this experiment were merely different positions within the same field. The same soil type, climate and husbandry variables were given. Although there was often substantial variation between individual samples within the variety means, the crop trial blocking factor did not give any consistent differences.

6.0 Conclusions

1. A crop growth trial compared 6 wheat varieties. The varieties all had similar proximate compositions, except for expected differences due to genotype in crude protein, Hagberg falling number and endosperm hardness.

2. The growth rates and feed intakes of growing broilers were not ($P>0.05$) altered when they were fed the 6 different varieties from 3 different field trial blocks.

3. There were differences ($P<0.05$) in broiler feed conversion ratios when fed the 6 different wheat varieties.

4. One wheat variety, Riband, had a low soluble NSP content and the birds fed this wheat variety had a low digesta viscosity. However, the weight gains, feed conversion ratios and efficiency of carcass energy retention was not ($p>0.05$) lower in this treatment group.

5. There were no differences in the determined apparent metabolisable energy, (AME), of the 6 wheat varieties, but there were significant

differences in the carcass energy retention per MJ of ME eaten. The differences in the efficiency of energy utilization were not correlated to the non-starch polysaccharide contents of the wheat samples. This was true for all other measures of chemical or physical characteristics of the wheat samples.

7.0 References

Adams, C.A. & Pugh, R. (1993). Non-starch polysaccharides and their digestion in poultry. Feed Compounder. Jan 1993. 19-21.

Aman, P. (1988). Cited in Wiseman, J. (1990). Quality requirements of wheat for poultry feed. Cereal Quality II. Milford, G.F.J., Kettlewell, P.S., Orson, J.H., Thomas, W.T.B., Pritchard, P.E., Myram, C. (Eds). AAB, Warwick.

Angkanaporn, K., Choct, M., Bryden, W.L., Annison, E.F. (1994). Effects of wheat pentosans on endogenous amino acid losses in chickens. Journal of Science Food Agriculture. 66: 399-404.

Annison, G. (1993). The role of Wheat Non-Starch Polysaccharides in Broiler Nutrition. Australian Journal of Agricultural Research: 44: 405-422.

Antoniou, T., Marquardt, R.R. & Cansfield, P.E. (1981). Isolation, partial characterisation and antinutritional activity of a factor (pentosans) in rye grain. Journal of Agricultural Food Chemistry. 29: 1240-1247.

Antoniou, T. & Marquardt, R.R. (1981). Influence of rye pentosans on the growth of chicks. Poultry Science. 60: 1898-1904.

Batterham, E.S., Lewis, C.E., McMIllan, C.J. (1976). Cited by Wiseman, J. (1990). Quality requirements of wheat for poultry feed. Cereal Quality II. Milford, G.F.J., Kettlewell, P.S., Orson, J.H., Thomas, W.T.B., Pritchard,

P.E., Myram, C. (Eds). AAB, Warwick.

Bechtel, D.B., Zayas, I., Kaleikau, I., Pomeranz, Y. (1990). Size distribution of wheat starch granules during endosperm development. Cereal Chemistry 67: 1: 59-63

Bedford, M.R. (1996). The effects of enzymes on digestion. Applied Poultry Research. 5: 4: 370.

Bedford, M.R. (1996). interaction between ingested feed and the digestive system in poultry. Journal of Applied Poultry Research. 5: 86-95.

Bedford, M.R. (1992). The effect of dietary enzymes on digestion in poultry. Feed Compounder. November 1992. 24-27.

Bell, D.J. & Freeman, B.M. (1971). Physiology and Biochemistry of the Domestic Fowl. Vol 1. Academic Press, London.

Bingham, S. (1987). Definitiona and intakes of dietary fibre. American Journal of Clinical Nutrition. 45: 1226-1231.

Bolton, W. (1955). Cited by Wiseman, J. (1990). Quality requirements of wheat for poultry feed. Cereal Quality II. Milford, G.F.J., Kettlewell, P.S., Orson, J.H., Thomas, W.T.B., Pritchard, P.E., Myram, C. (Eds). AAB, Warwick.

Bolton, W. & Blair, R. (1974). Poultry Nutrition. Bulletin 174. MAFF,

London.

Briggle. & Curtis. (1987). Heyne, (Ed). Wheat and Wheat Improvement. 2nd Ed. American Society of Agriculture.

Bushuk, W. & Rasper, V.F. (Eds). (1994). Wheat Production Properties and Quality. 1st Ed. Blackie Academic-Professional, Glasgow.

Choct, M., Hughes, R.J., Trimble, P., Angkanaporn, K., Annison, G. (1994). Non-starch polysaccharide-degrading enzymes increase the performance of broiler chickens fed wheat of low apparent metabolisable energy. American Institute of Nutrition. 1995.

Choct, M., Hughes, R.J. and Bedford, M.R. (1996). Effects of feed enzymes on between bird variation and ileal caecal volatile fatty acid levels in broilers fed wheat. in. Proceedings of the XX World's Poultry Congress, New Delhi, India. pp218-219. Vol IV. World's Poultry Science Association (India Branch).

Choct, M. & Annison, G. (1992). The inhibition of nutrient ingestion by wheat pentosans. British Journal of Nutrition 67: 123-132.

Choct, M. & Annison, G. (1990). Anti-nutritive activity of wheat pentosans in broiler diets. British Poultry Science 31: 811-821.

Choct, M. & Annison, G. (1992). Anti-nutritive effect of wheat pentosans in broiler chickens: Roles of viscosity and gut microflora. British Poultry

Science. 33: 821-834.

Classen, H.L. & Bedford, M.R. (1991). The use of enzymes to improve the nutritive value of poultry feeds. Recent Advances in Abimal Nutrition. Haresign, W. & Cole, D.J.A. (Eds). Butterworths, London.

Collier, J., Rose, S.P., Kettlewell, P.S., Bedford, M.R. (1996). Wheat varieties and the energy retention of broiler chickens. British Poultry Science Vol 37 Supplement 1996.

Edwards *et al.* (1988). Do viscous polysaccharides slow absorption by inhibiting diffusion or convection. European Journal of Clinincal Nutrition. 42: 306-

Englyst, H.N., Bingham, S.A., Runswick, S.A., Collinson, E., Cummings, J.H. (1989). Dietary fibre (non-starch polysaccharides) in cereal products. Journal of Human Nutrition and Dietetics. 2: 253-271.

Englyst, H.N., Anderson, V., Cummings, J. (1983). Starch and non-starch polysaccharides in some cereal foods. Journal of Science of Food and Agriculture. 34: 1434-1440.

Eves, Bechtel, D.B. (1988). Cited by Pomeranz, Y. (1988). Wheat, Chemistry and Technology. 3rd Ed. American Association.

Farrent. (1993). Cited by Rose, S.P., Fielden, M., Foote, W.R., Gardin, P. (1995). Sequential feeding of whole wheat to growing broiler chickens.

British Poultry Science. 36: 1: 97-111.

Fenwick, R.D. (1990). The quality potential of current cereal varieties. Quality requirements of wheat for poultry feed. Cereal Quality II. Milford, G.F.J., Kettlewell, P.S., Orson, J.H., Thomas, W.T.B., Pritchard, P.E., Myram, C. (Eds). AAB, Warwick.

Fincher. & Stone. (1986). Cited by Pomeranz, Y. (1988). Wheat, Chemistry and Technology. 3rd Ed. American Association.

Fisher, C. (1989). Energy evaluations of poultry rations. Recent Developments in Poultry Nutrition. Cole, D.J.A. & Haresign, W. (Eds). Butterworths, London.

Fisher, C. & McNab, J.M. (1989). Techniques for determining the metabolisable energy content of poultry feeds. Recent Developments in Poultry Nutrition. Cole, D.J.A. & Haresign, W. (Eds). Butterworths, London.

Fraps, G.S. (1946). Composition and productive energy of poultry feeds and rations. Bulletin No 678. Texas Agricultural Experiment Station.

Graham, H,. (1994). Foregut digesta viscosity affects broiler performance. Zootechnica International, Jan 1994.

Halveson, J. & Zeleny, L. (1988). Cited by Pomeranz, Y. (1988). Wheat, Chemistry and Technology. 3rd Ed. American Association.

Hill, F.W. & Anderson, D.L. (1958). Comparison of metabolisable energy and productive energy determinations with growing chicks. Journal of Nutrition. 64: 587-603.

Ikeda & Kusani (1983). Cited by Choct, M. & Annison, G. (1992). The inhibition of nutrient ingestion by wheat pentosans. British Journal of Nutrition 67: 123-132.

Ikegami *et al.* (1990). Cited by Choct, M. & Annison, G. (1992). The inhibition of nutrient ingestion by wheat pentosans. British Journal of Nutrition 67: 123-132.

Izydorczyk, M., Biliaderis, C.G., Bushuk, W. (1991). Physical properties of water-soluble pentosans from different wheat varieties. Cereal Chemistry. 68 (2): 145-150

Kent. (1966). Cited by Pomeranz, Y. (1988). Wheat, Chemistry and Technology. 3rd Ed. American Association..

Larbier, M. & LeClercq, B. (1994). Nutrition and Feeding of Poultry. Wiseman, J. (Ed). Nottingham University Press.

Leeson, S. & Summers, J.D. (1997).Commercial Poultry Nutrition. 2nd Ed. University Books, Ontario.

Lersten. (1987). Cited by Briggle. & Curtis. (1987). Heyne, (Ed). Wheat and Wheat Improvement. 2nd Ed. American Society of Agriculture

Livesay, G., Smith, T., Eggum, B.O., Tetens, I.H., Nyman, M., Roberfroid, M., Delzenne, N., Schweizer, T.F., Decombaz, J. (1995). Determination of digestible energy values and fermentabilities of dietary fibre supplements: a European interlaboratory study *in vivo*. British Journal of Nutrition. 74: 289-302.

Longstaff, M. & McNab, J.M. (1986). Cited by Wiseman, J. (1990). Quality requirements of wheat for poultry feed. Cereal Quality II. Milford, G.F.J., Kettlewell, P.S., Orson, J.H., Thomas, W.T.B., Pritchard, P.E., Myram, C. (Eds). AAB, Warwick

MAFF (1995). Agriculture in the UK, HMSO, London.

March, B.E. & Biely, J. (1973). Chemical, Physical, and Nutritional Characteristics of Different Samples of Wheat. Canadian Journal of Animal Science. 53: 569-577.

March, B.E. & Biely, L. (1973). Chemical, physical and nutritional characteristics of different samples of wheat. Canadian Journal of Animal Science. 53: 569-577

Matz, S.A. (1991). The Chemistry and Technology of Cereals as Food and Feed. 2nd Ed. AVI.

Maynard, L.A. & Loosli, J.K. (1962). Animal Nutrition. 5th Ed. McGraw - Hill Book Co, INC. New York.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D. (1988). Animal Nutrition. 4th ed. Longman, Harlow, Essex

McNab, J. (1991). Factors affecting the nutritive value of wheat for poultry. HCGA Project Report No. 43.

Mollah, Y. (1980). ME of poultry diets on relation to cereal carbohydrates and their interactions. PhD Thesis. University of Sydney.

Mollah *et al* (1990) Cited by Wiseman, J. (1990). Quality requirements of wheat for poultry feed. Cereal Quality II. Milford, G.F.J., Kettlewell, P.S., Orson, J.H., Thomas, W.T.B., Pritchard, P.E., Myram, C. (Eds). AAB, Warwick

North, M.O. (1984). Commercial Chicken Production Manual. 3rd Ed. AVI Publishing Co, Westport, Connecticut.

Nuttonson. (1955). Cited by Briggle. & Curtis. (1987). Heyne, (Ed). Wheat and Wheat Improvement. 2nd Ed. American society of Agriculture.

Oleson. (1994). Cited by Bushuk, W. & Rasper, V.F. (Eds). (1994). Wheat Production Properties and Quality. 1st Ed. Blackie Academic-Professional, Glasgow.

Orth & Shellenberger. (1984). Cited by Pomeranz, Y. (1988). Wheat, Chemistry and Technology. 3rd Ed. American Association.

Percival, J. (1934). Wheat in Great Britain. Duckworth, London.

Percival, J. (1921). Cited by Briggle. & Curtis. (1987). Heyne, (Ed). Wheat and Wheat Improvement. 2nd Ed. American society of Agriculture

Pomeranz, Y. (1988). Wheat, Chemistry and Technology. 3rd Ed. American Association.

Rogel, A.M., Annison, E.F., Bryden, W.l. and Balnave, D. (1987). The digestion of wheat starch in broiler chickens. Australian Journal of Agricultural Research, 38: 639-649.

Rose, S.P. (1997). Principles of Poultry Science. CAB International, Wallingford, Oxon, UK.

Rose, S.P. & Parker, J. (1990). Evaluation of a diet selection technique to compare the nutritional value of feed wheats for poultry. Cereal Quality II. Milford, G.F.J., Kettlewell, P.S., Orson, J.H., Thomas, W.T.B., Pritchard, P.E., Myram, C. (Eds). AAB, Warwick.

Rose, S.P., Fielden, M., Foote, W.R., Gardin, P. (1995). Sequential feeding of whole wheat to growing broiler chickens. British Poultry Science. 36: 1: 97-111.

Rose, S.P. & Bedford, M.R. (1995). Relationship between the metabolisable energies of wheat samples and the productive performance of broilers. British Poultry Science. 36: 865-867.

Salah Uddin, M., Rose, S.P., Hiscock, T.A., Bonnet, S. (1996). A comparison of the energy avilability for chickens of ground and whole grain samples of two wheat varieties. British Poultry Science. 37: 2:347-357.

Sibbald, I.R. (1989). Metabolisable energy evaluation of poultry diets. Recent Developments in Poultry Nutrition. Cole, D.J.A. & Haresign, W. (Eds). Butterworths, London.

Sibbald, I.R. & Price , K. (1962) Cited by Wiseman, J. (1990). Quality requirements of wheat for poultry feed. Cereal Quality II. Milford, G.F.J., Kettlewell, P.S., Orson, J.H., Thomas, W.T.B., Pritchard, P.E., Myram, C. (Eds). AAB, Warwick

Sturkie, P.D. (1965). Avian Physiology. 2nd Ed. Bailliere, Tindall & Cassell, London.

Sulaiman, B.D., Brennan, C.S., Schofield, J.D., Vaughan, J.G. (1993). Some biochemical properties of friabilin and polyclonal antibody production. Aspects of Applied Biology. 36: 61-67.

Waldron, L.A. (1997). The nutritive value of different wheat varieties for broiler chickens. Ph. D. Thesis. Harper Adams Agricultural College.

Waldron, L.A., Rose, S.P. & Kettlewell, P.S. (1993). Differences in the productive performance of broiler chickens fed two wheat varieties. Aspects of Applied Biology. 36: 485-489.

Waldron, L.A., Rose, S.P. & Kettlewell, P.S. (1994). The effects of feeding two wheat varieties from two growing years on the productive performance and digesta viscosity of broiler chickens at three ages. Proceedings of the 9th European Poultry Conference. vol 1 pp 485-486. Walker & Connell - Ltd., U.K.

Waldron, L.A., Rose, S.P., Kettlewell, P.S. (1994). Nutritive value of wheat for poultry with respect to wheat variety and growing year. British Poultry Science. 35: 813-835.

Ward, A.T. & Marquadt, R.R. (1987). Antinutritional activity of a water soluble pentosan rich fraction from rye grain. Poultry Science. 66: 1665-1674.

Wiseman, J. & Inborr, J. (1990). The nutritive value of wheat and its effect on broiler performance. Recent Advances in Abimal Nutrition. Haresign, W. & Cole, D.J.A. (Eds). Butterworths, London.

Wiseman, J. (1990). Quality requirements of wheat for poultry feed. Cereal Quality II. Milford, G.F.J., Kettlewell, P.S., Orson, J.H., Thomas, W.T.B., Pritchard, P.E., Myram, C. (Eds). AAB, Warwick.

van Paridon, P.A., Boonman, J.C.P., Selten, G.C.M., Geerse, C., Barug, D., de Bot, P.H.M., Hemke, G. (1992). The application of fungal endoxylanase in poultry diets. Xylans and Xylanases. Visser, J. (Ed). Elsevier Science Publishers B.V.

Veldman, A. & Vahl, H.A. (1994). Xylanase in broiler diets with differences in characteristics and content of wheat. British Poultry Science. 35: 537-550.

Voragen, A.G.J., Gruppen, H., Verbruggen, M.A. & Viëtor, R.J. (1992). Characterization of cereal arabinoxylans. Xylans and Xylanases. Visser, J et al. (Ed). Elsevier Science Publishers. B.V.